525 Rec'd PCT/PTO 27 NOV 2000

FORM PTO-1390 (Modified)
(REV 11-98)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
587-68 EPO/PCT/US

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
09/701223

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US99/11617	26 May 1999 (26.05.99)	27 May 1998 (27.05.98)

TITLE OF INVENTION
APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM

APPLICANT(S) FOR DO/EO/US
Robert De Tullio; Mark Greening; Jiliang Yu and John Kelvin Fidler

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ has been transmitted by the International Bureau.
   - c. ☒ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☐ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☒ Certificate of Mailing by Express Mail
20. ☒ Other items or information:

(1) Copy of the international application as published on 2 December 1999 under publication number WO 99/62188.
(2) Copy of Article 34 Amendment.

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U.S. APPLICATION NO (IF KNOWN, SEE 37 CFR 09/701223	INTERNATIONAL APPLICATION NO. PCT/US99/11617	ATTORNEY'S DOCKET NUMBER 587-68 EPO/PCT/US

21. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

	CALCULATIONS	PTO USE ONLY
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1,000.00**		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but Internation Search Report prepared by the EPO or JPO **$860.00**		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**		
☒ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	**$690.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	13 - 20 =	0	x $18.00	**$0.00**	
Independent claims	4 - 3 =	1	x $80.00	**$80.00**	
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$770.00**	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).** ☐				**$0.00**	
SUBTOTAL =				**$770.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$770.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$770.00**	
				Amount to be: refunded	$
				charged	$

☒ A check in the amount of **$770.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **08-2461** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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30,449

REGISTRATION NUMBER

November 27, 2000

DATE

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PATENT

IN THE U.S. DESIGNATED/ELECTED OFFICE OF THE PCT

IN RE APPLICATION OF: :
Robert De Tullio, et al.

INTERNATIONAL APPLICATION :
NUMBER: PCT/US99/11617 :

INTERNATIONAL FILING DATE: :
26 May 1999 :

FOR: APPARATUS AND METHOD FOR :
TESTING A TELECOMMUNICATIONS:
SYSTEM :

Assistant Commissioner for Patents
BOX PCT
Washington, DC 20231
ATTENTION: DO/EO/US

EXPRESS MAIL CERTIFICATE OF MAILING
FOR ABOVE-IDENTIFIED APPLICATION

"Express Mail" mailing label number: EL633571378US

Date of Deposit: November 27, 2000

I hereby certify that the enclosed Transmittal Letter to the United States Designated/Elected Office Concerning a Filing Under 35 U.S.C. 371 (in duplicate); copy of International Publication Number WO 99/62188; International Search Report; copy of Article 34 Amendment; check for $770.00; and return receipt postcard is deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 C.F.R. §1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, DC 20231.

Lisa Bartell
Printed Name of person mailing paper

Lisa Bartell
Signature of person mailing paper

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IN THE INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY

Applicant:	Porta Systems Corporation, et al.
Authorized Officer:	Curtis Kuntz/Rugenia Logan
International Application No.:	PCT/US99/11617
Group Art Unit:	Unassigned
Int'l Filing date:	May 26, 1999
Docket:	587-68 EPO/PCT
Dated:	September 15, 2000
For:	APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM

Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

RESPONSE TO WRITTEN OPINION

Sir:

Applicants request amendment of the above-identified International Application under Article 34 as set forth below:

In the Claims:

Please substitute Application pages 20-22 with replacement sheets 20-22.

REMARKS

This Amendment to the International Application under Article 34 replaces originally filed Claims 3-7 with amended claims bearing the same numbers. These amendments have previously been submitted in an Amendment under Article 19, which was filed in the

I hereby certify this correspondence is being deposited with the United States Postal Service as first class mail, postpaid in an envelope, addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231 on September 15, 2000
Dated: 9/15/00, Julie L. Watts

International Bureau on February 15, 2000. However, in view of the Examiner's comments in the Written Opinion concerning Claim 4, Applicants hereby resubmit the amendments contained herein.

Applicants respectfully request entry and consideration of this Amendment under Article 34 in preparing the International Preliminary Examination Report.

Respectfully submitted,

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CLAIMS

1. A method of testing a telecommunications system, the method comprising;

1) applying a first AC test signal having a first signal frequency to the system and measuring the response of the system to the first test signal;

2) applying a second AC test signal having a second signal frequency different to the first signal frequency to the system and measuring the response of the system to the second test signal; and

3) calculating one or more parameters of the system from the responses measured in steps 1) and 2).

2. A method according to claim 1 wherein the first and second test signals are applied at different times.

3. A method according to claim 1 wherein one or both of the test signals has a substantially sinusoidal waveform.

4. A method according to claim 1 wherein less than five cycles of each signal is applied to the system.

5. A method according to claim 1 wherein the test signals are each applied to the system through a known impedance.

6. A method according to claim 1 further comprising applying;

4) applying one or more additional test signals to the system and measuring the response of the system to at least one test signal; and

wherein step 3) comprises calculating one or more parameters of the system from the responses measured in steps 1),2) and 4).

7. A method according to claim 1 wherein the system comprises first and second transmission lines, and wherein each step of applying a test signal and measuring the response of the system comprises

a) applying the test signal to the first line and monitoring the response of the first line and the second line to the test signal; and

b) applying the test signal to the second line and monitoring the response of the second line and the first line to the second test signal.

8. A method of testing a telecommunications system comprising first and second transmission lines, the method comprising

1) applying a first test signal to the first line and measuring the response of the first line and the second line to the first test signal;

2) applying a second test signal to the second line and measuring the response of the second line and the first line to the second test signal; and

3) calculating one or more parameters of the telecommunications system from the responses measured in steps 1) and 2).

9. A method according to claim 8 wherein the first and second signals each comprise AC signals.

10. A method according to claim 9 wherein the signal frequencies of the first and second test signals are substantially identical.

11. A method according to claim 10 wherein the first and second test signals have a known phase relationship.

12. Apparatus for testing a telecommunications system, the apparatus comprising;

1) means for applying a first AC test signal having a first signal frequency to the system;

2) means for measuring the response of the system to the first test signal;

3) means for applying a second AC test signal having a second signal frequency different to the first signal frequency to the system;

4) means for measuring the response of the system to the second test signal; and

5) means for calculating one or more parameters of the system from the responses measured in steps 1) and 2).

13. Apparatus for testing a telecommunications system comprising first and second transmission lines, the apparatus comprising

1) means for applying a first test signal to the first line

2) means for measuring the response of the first line and the second line to the first test signal;

3) means for applying a second test signal to the second line;

4) means for measuring the response of the second line and the first line to the second test signal; and

5) means for calculating one or more parameters of the telecommunications system from the responses measured in steps 1) and 2).

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APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM

The present invention relates to a method and apparatus for testing a telecommunications system.

Conventional apparatus for testing telecommunications systems applies a test signal to the telecommunications system and, by analysing the response of the system to the test signal, calculates one or more parameters of the system in accordance with a chosen line model.

A problem with conventional methods is that it is not possible to determine the series line resistance of a transmission line in the system under test.

In accordance with a first aspect of the present invention there is provided a method of testing a telecommunications system, the method comprising;

1) applying a first AC test signal having a first signal frequency to the system and measuring the response of the system to the first test signal;

2) applying a second AC test signal having a second signal frequency different to the first signal frequency to the system and measuring the response of the system to the second test signal; and

3) calculating one or more parameters of the system from the responses measured in steps 1) and 2).

The first aspect of the present invention provides additional data which can be analyzed to calculate system parameters (e.g. electrical parameters such as resistance or capacitance) which have been previously difficult or impossible to determine - such as series line resistance.

The first and second AC test signals may be applied at the same time, in the form of a multi-frequency signal. However preferably the first and second test signals are applied at different times.

The wave form of the first and/or second test signal may be non-sinusoidal (for instance a square wave or saw-tooth wave) but preferably the test signals have a

substantially sinusoidal waveform. This simplifies the calculation procedure.

It is important that the method can test the telecommunications system quickly - this enables a number of lines within the system to be tested over a given period. Therefore preferably less than 5 cycles of each signal is applied to the system. In a preferred embodiment, two cycles of each signal are applied to the system.

Typically the test signals are each applied to the system through a known impedance. The voltage drop across the known impedance can then be used to calculate a characteristic impedance of the telecommunications system.

If additional data is required, then one or more additional test signals may be applied to the system. The one or more additional test signals may comprise AC test signals with a signal frequency different to the signal frequency of the first and second test signals. However preferably the or each additional test signal comprises a DC test signal.

Typically the system comprises first and second transmission lines (conventionally known as A and B lines). Conventionally an AC test signal is applied simultaneously to both lines (either in phase or in anti-phase) and the response of only one of the lines is monitored. In a preferred embodiment the step of applying a test signal and measuring the response of the system comprises:

a) applying the test signal to the first line and monitoring the response of the first line and the second line to the test signal; and
b) applying the test signal to the second line and monitoring the response of the second line and the first line to the second test signal.

By monitoring the response of both lines, additional parameters can be obtained.

In accordance with a second aspect of the present invention there is provided a method of testing a

telecommunications system comprising first and second transmission lines, the method comprising

1) applying a first test signal to the first line and monitoring the response of the first line and the second line to the first test signal;

2) applying a second test signal to the second line and monitoring the response of the second line and the first line to the second test signal; and

3) calculating one or more parameters of the telecommunications system from the responses measured in steps 1) and 2).

The second aspect of the present invention enables a number of system parameters to be calculated. In contrast with conventional systems, the response of both the first line and the second line is monitored.

The first and second signals may be DC signals, or alternatively the first test signal and/or the second test signal may comprise an AC signal. In a preferred example the signal frequencies of the first and second test signals are substantially identical. Alternatively, the signal frequency of the first and second test signals may be different.

The first and second test signals may be generated independently, but preferably they have a known phase relationship. This enables the parameters to be calculated more easily in step 3).

A number of embodiments of the present invention will now be described with reference to the accompanying drawings in which:-

Figure 1 is a schematic illustration of apparatus for testing a telecommunications system;

Figure 2 illustrates the remote test unit, exchange and telephone in more detail;

Figure 3 illustrates the functional structure of the remote test unit;

Figure 4 is a schematic diagram illustrating the arrangement of the line test unit;

Figure 5 illustrates part of the measurement cycle;

Figure 6 illustrates the full complex voltages measured by the AC measurement cycle;

Figure 7 is a first example of a line model;

Figure 8 is an enhanced line model;

Figure 9 is a line termination model, discussed in Appendix 4; and

Figure 10 is a third example of a line model.

Figure 1 is a schematic diagram of a system for remotely testing a telecommunications line. An operator station 1 is connected to a general controller 2 which inputs and outputs signals to/from a telecommunications medium 3 (which may comprise a PSTN or X.25 network). A telephone 6 is connected to a local exchange 5 via a land line 7. A remote test unit (RTU) 4 is connected to the exchange 5 in order to test the land line 7. Figure 1 illustrates a control path 8 and a test path 9.

As can be seen in Figure 2, the line 7 comprises a pair of lines 10,11 (configured as a twisted pair) known conventionally as "A" and "B" lines. An exchange feed comprising a 50V battery 12 is connected to the A and B lines 10,11 during normal operation via 200 ohm resistors 13,14. In order to test the line 7, the RTU control line 8 switches the A and B lines 10,11 over to the test line 9 (which in turn comprises a pair of input lines 15,16). The RTU communicates with the general controller 2 via a V.24 link (17) or 300 V.21 link (18).

The internal functional structure of the RTU 4 is shown in Figure 3. The A and B input lines 15,16 are connected to a line access unit 19 which controls the input and output of signals to/from the line 7. A line test unit 22 controls testing of the line 7, a tone generator 23 generates tone signals 24 which can be output onto the line 7, and voice modems 25,26 handle voice signals which can be communicated between the operator station 1 and telephone set 6. The RTU is controlled by a microprocessor 20 and data acquired is saved in a memory 21.

The line test unit 22 is illustrated in more detail in Figure 4. A pair of signal generators 30,31 generate sine wave signals which are amplified by respective amplifiers 32,33. The signals output by amplifiers 32,33 have a range of +/-200V and a bandwidth of 10kHz. The signal generators 30,31 are run synchronously from the same clock by a controller 34. This ensures that the signals have a known phase relationship. Each line has a respective set of output resistors 35-40 (each having a known resistance within a tolerance of 1%). Each output resistor has an associated switch 41-46 which can be closed by controller 34 to connect the associated output resistor between the amplifier and output line 47,48. Typical resistance values for the three output resistors on each line are 200,1M and 100K ohms. The voltage on line A is measured by a voltmeter 49 and the voltage on line B is measured by a voltmeter 50. The voltages are digitised by A-D converter 51 which samples at 12 kHz. Phase and RMS voltage values are calculated by processor 52 and stored in memory 53.

Referring to Figure 5, the line test procedure is as follows:

Step 1 - open all output resistor switches 41-46 and measure DC voltage on A and B lines.

Step 2 - adjust DC bias of amplifier 32 so that amplified signal is centred on line A DC voltage level.

Step 3 - adjust DC bias of amplifier 33 so that amplified signal is centred on line B DC voltage level.

Step 4 - set signal generators 30,31 to generate a DC signal.

Step 5 - close a selected one of the line A output resistor switches 41-43.

Step 6 - store DC voltages on voltmeters 39,50 in memory 53.

Step 7 - open selected line A switch and close a selected one of the line B output resistor switches 44-46.

Step 8 - store DC voltages on voltmeters 39,50 in memory 53.

Step 9 - set signal generators 30,31 to 2.75Hz.

Step 10 - after first cycle, perform digital fourier transform (at 2.75Hz) of signals from voltmeters 49,50 over second cycle and store amplitude and phase values in memory 53.

Step 11 - open selected switch 44-46 (line B) and close switch 41-43 associated with selected output resistor (line A).

Step 12 - after first cycle, perform digital fourier transform (at 2.75Hz) of signals from voltmeters 49,50 over second cycle and store amplitude and phase values in memory 53.

Step 13 - adjust frequency of signal generators 30,31 to 5Hz.

Steps 14-16 - repeat steps 10-12 at 5Hz.

The resulting AC data can be represented as four complex voltage values as illustrated in Figure 6, where:

V_{A1} is the voltage measured by voltmeter 49 (line A) with signal being applied to line A;

V_{B1} is the voltage measured by voltmeter 50 (line B) with signal being applied to line A;

V_{A2} is the voltage measured by voltmeter 49 (line A) with signal being applied to line B; and

V_{B2} is the voltage measured by voltmeter 50 (line B) with signal being applied to line B.

The four complex values can then be used to calculate four impedance parameters Z as defined below:

$Z_{11}=V_{ae}/I_a$ when line b is open;

$Z_{22}=V_{be}/I_b$ when line a is open;

$Z_{12}=V_{ae}/I_b$ when line a is open; and

$Z_{21}=V_{be}/I_a$ when line b is open;.

where

V_{ae} is the voltage on voltmeter 49 (ie. the voltage from line A to earth);

V_{be} is the voltage on voltmeter 50 (ie. the voltage from line B to earth);

I_a is the current on line 47 (line A); and

I_b is the current on line 48 (line B).

Since the voltages (V_a, V_b) output by the amplifiers 32,33 and the values (R_a, R_b) of the resistors 35-40 are known accurately, the currents I_a and I_b can be eliminated from the expressions for Z as follows:

$Z_{11}=R_aV_{ae}/(V-V_{ae})$;

$Z_{22}=R_bV_{be}/(V-V_{be})$;

$Z_{12}=R_bV_{ae}/(V-V_{be})$; and

$Z_{21}=R_aV_{be}/(V-V_{ae})$.

Once the Z parameters have been calculated as discussed above, they can be used to determine characteristics of the line 7 under test using an algorithm based on a selected line model.

One example of a suitable line model is illustrated in Figure 7. The series resistances of the lines 10,11 between the RTU 4 and the telephone 6 are represented by resistors R_1, R_2. The line termination at telephone 6 is represented by resistors R_5, R_6 and capacitors C_2, C_3. The leakage to ground from the A and B lines is represented by resistors R_3, R_4 and capacitors C_1, C_2. The problem with the line model of Figure 7 is that it is difficult to find ten independent equations based on conventional tests in order to calculate the ten line model parameters. Even if ten independent equations could be found, it would be difficult to solve the ten non-linear equations even by a numerical method.

The alternative line model of Figure 8 reduces the number of parameters to be identified by replacing the line termination parameters R_5, R_6, C_2 and C_3 with a single impedance value Z. In Figure 8 the series resistances of the lines 10,11 between the RTU 4 and the telephone 6 are represented by resistors r_1, r_2 and the leakage to ground from the A and B lines is represented by resistors g_1, g_2 and capacitors C_1, C_2.

A set of equations based on the enhanced line model of Figure 8 can be manipulated into a linear equation system

and a set of symbolic solutions obtained as set out in Appendix 1, Appendix 2 and Appendix 3 below.

Furthermore, the line termination parameters can also be calculated as set out in Appendix 4 below.

The calculated values of the parameters r_1, r_2, g_1, g_2, c_1, c_2 and z are stored at the RTU for later analysis or transmitted back to the operator station 1. The parameters can then bé used to identify and characterise any faults on the line 7 such as a break in the line, fault to ground or fault to another line. Furthermore the parameters can be used to determine whether the line 7 is suitable for carrying different communication protocols such as ISDN,DACS,HDSL,CWSS or ADSL.

A further alternative line model is illustrated in Figure 10. It is possible to calculate the parameters of this model using a simplified measurement procedure which uses a DC measurement followed by a single AC measurement (ie. at only one frequency).

Although the line test unit 22 illustrated in Figure 4 is shown with two signal generators 30,31 and two sets of output resistors 41-46, it will be appreciated that a single generator and a single set of resistors could be used, and switched from one line to the other.

Appendix 1

Identification Results

The model parameters including the series resistances are given as follows,

$$r_1 = \frac{n_1 Z_{11b} + Z_{11a}\omega n_2 + \omega n_3 Z_{12a} + Z_{12b}}{\omega n_2} \tag{1}$$

$$r_2 = \frac{n_1 Z_{11b} + Z_{22a}\omega n_1 + \omega n_2 Z_{12a} + Z_{22b}}{\omega n_2} \tag{2}$$

$$g_2 = -\frac{\omega n_2}{(n_1)^2 Z_{11b} + n_1 n_3 Z_{12a}\omega + n_3 Z_{12b} - n_2 Z_{12a}\omega + n_2 n_3 Z_{12b}(\omega)^2 + (n_2)^2 Z_{11b}(\omega)^3} \tag{3}$$

$$g_1 = n_1 g_2$$

$$c_1 = n_2 g_2 \tag{4}$$

$$c_2 = n_3 g_2 \tag{5}$$

$$Z = \frac{\dfrac{1}{Z_{12}} - g_1 - g_2 - j\omega c_1 - j\omega c_2}{(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \tag{6}$$

where ω is test frequency, Z_{ija} and Z_{ijb}, $i=1,2$, $j=1,2$ are the real and imaginary parts of the Z-parameters respectively, and n_k, $k=1,2,3$ can be calculated from the knowns, whose expressions along with the detailed mathematical manipulations were given in the appendix.

An example

For a simple example to show that the proposed method can solve the problem, let us suppose that

$$r_1 = r_2 = 1,$$
$$g_1 = 2,$$
$$g_2 = 3,$$
$$c_1 = 2,$$
$$c_2 = 4,$$
$$Z = \frac{1 - j\omega}{4}$$

For this simple example, the measurements of Z-parameters can be easily simulated by simple calculation as indicated in (7)-(9) in the appendix. They are,

$$\omega = 1,$$

$$Z_{11a} = \frac{377}{328}$$

$$Z_{11b} = \frac{-51}{328}$$

$$Z_{12a} = \frac{2}{41}$$

$$Z_{12b} = \frac{-5}{82}$$

$$Z_{22a} = \frac{45}{41}$$

$$Z_{22b} = \frac{-5}{41}$$

$$\omega_2 = 2$$

$$Z^2_{11a} = \frac{10145}{9442}$$

$$Z^2_{11b} = \frac{-711}{4721}$$

$$Z^2_{12a} = \frac{50}{4721}$$

$$Z^2_{12b} = \frac{-128}{4721}$$

$$Z^2_{22a} = \frac{4896}{4721}$$

$$Z^2_{22b} = \frac{-488}{4721}$$

substitue them to (27) to (35) to calculate coefficients (See appendix 2 for definition) we get

$$a_1 = \frac{116037}{1548488}$$

$$a_2 = \frac{7392}{193561}$$

$$a_3 = \frac{11709}{193561}$$

$$d_1 = \frac{225645}{1548488}$$

$$d_2 = \frac{-124167}{774244}$$

$$d_3 = \frac{-2613}{387122}$$

$$d_5 = \frac{13131}{193561}$$

$$d_6 = \frac{-28842}{193561}$$

By further substituting to (46) to (48) we get

$$n_1 = \frac{2}{3}$$

$$n_2 = \frac{2}{3}$$

$$n_3 = \frac{4}{3}$$

So we can calculate r_1 and r_2 from (50) and (51), the results are

$$r_1 = 1$$

$$r_2 = 1$$

and g2 from (52)

$g_2=3$

from (43) to (45)

$g_1=2$

$c_1=2$

$c_2=4$

which are exactly the same as our assumption. For a more practical example, the results' accuracy relies heavily on the precision of the software. It needs to be studied that what precision is needed for our test purpose.

Discussion and conclusions

- In the report, we suppose that two frequencies are used in the measurements. It is noticed that one of them can be zero, that means we can use a DC test and an AC test to identify all the parameters. But in this case, the formulas are more complicated as less information obtained. In fact, a second order, two variables non-linear equation system has to be solved, maybe numerically. Further study is carrying out along this direction hoping find a way to find a relatively simple symbolic solution.
- The calculation can be further reduced as we use two frequencies with one doubles the other, which is the case in the current test system.
- It is possible to locate leakage fault by using the series resistance.
- The line termination parameters, which are represented by a combined impedance Z in our discussion, can be further identified
- It can be concluded that all the parameters in the enhanced line model can be uniquely identified with two frequencies measurements. For the DC and AC case, the line parameter and the combined line termination can be identified, but the individual line termination parameters remain unsolved

Appendix 2

For a two port network as shown in Figure 8 the Z-parameters can be calculated as follows,

$$
\begin{aligned}
Z_{11} &= r_1 + \frac{\dfrac{1}{g_1 + j\omega c_1}\left(Z + \dfrac{1}{g_2 + j\omega c_2}\right)}{\dfrac{1}{g_1 + j\omega c_1} + Z + \dfrac{1}{g_2 + j\omega c_2}} \\
&= r_1 + \frac{(g_2 + j\omega c_2)Z + 1}{g_1 + g_2 + j\omega c_1 + j\omega c_2 + Z(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \qquad (7) \\
&= r_1 + \frac{(g_2 + j\omega c_2)Z + 1}{\Delta}
\end{aligned}
$$

$$
\begin{aligned}
Z_{12} &= \frac{\dfrac{1}{g_1 + j\omega c_1}\,\dfrac{1}{g_2 + j\omega c_2}}{\dfrac{1}{g_1 + j\omega c_1} + Z + \dfrac{1}{g_2 + j\omega c_2}} \\
&= \frac{1}{(g_1 + j\omega c)(g_2 + j\omega c_2)\left(\dfrac{1}{g_1 + j\omega c_1} + Z + \dfrac{1}{g_2 + j\omega c_2}\right)} \qquad (8) \\
&= \frac{1}{g_1 + g_2 + j\omega c_1 + j\omega c_2 + Z(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \\
&= \frac{1}{\Delta}
\end{aligned}
$$

$$
\begin{aligned}
Z_{22} &= r_2 + \frac{\dfrac{1}{g_2 + j\omega c_2}\left(Z + \dfrac{1}{g_1 + j\omega c_1}\right)}{\dfrac{1}{g_1 + j\omega c_1} + Z + \dfrac{1}{g_2 + j\omega c_2}} \\
&= r_2 + \frac{(g_1 + j\omega c_1)Z + 1}{g_1 + g_2 + j\omega c_1 + j\omega c_2 + Z(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \qquad (9) \\
&= r_2 + \frac{(g_1 + j\omega c_1)Z + 1}{\Delta}
\end{aligned}
$$

From (8) we can get,

$$Z(g_1 + j\omega c_1)(g_2 + j\omega c_2) = \frac{1}{Z_{12}} - g_1 - g_2 - j\omega c_1 - j\omega c_2 \qquad (10)$$

Rewritten (7) as:

$$Z_{11} = r_1 + [(g_2 + j\omega c_2)Z + 1]Z_{12}$$

multiply $(g_1+j\omega c_1)$, if $(g_1+j\omega c_1) \neq 0$, we get

$$
\begin{aligned}
(g_1 + j\omega c_1)Z_{11} &= r_1(g_1 + j\omega c_1) + (g_1 + j\omega c_1)[(g_2 + j\omega c_2)Z + 1]Z_{12} \\
&= r_1(g_1 + j\omega c_1) + [(g_1 + j\omega c_1)(g_2 + j\omega c_2)Z]Z_{12} + (g_1 + j\omega c_1)Z_{12} \qquad (11)
\end{aligned}
$$

substitute (10) to (11) to eliminate Z,

$$
\begin{aligned}
(g_1 + j\omega c_1)Z_{11} &= r_1(g_1 + j\omega c_1) + \left(\frac{1}{Z_{12}} - g_1 - g_2 - j\omega c_1 - j\omega c_2\right)Z_{12} + (g_1 + j\omega c_1)Z_{12} \\
&= r_1(g_1 + j\omega c_1) + 1 - (g_1 + j\omega c_1)Z_{12} - (g_2 + j\omega c_2)Z_{12} + (g_1 + j\omega c_1)Z_{12} \qquad (12) \\
&= r_1(g_1 + j\omega c_1) + 1 - (g_2 + j\omega c_2)Z_{12}
\end{aligned}
$$

Similarly we can get an equation about Z_{22} as

$$(g_2 + j\omega c_2)Z_{22} = r_2(g_2 + j\omega c_2) + 1 - (g_1 + j\omega c_1)Z_{12} \qquad (13)$$

We write the Z-parameters in their real and imaginary part as

$$
\begin{aligned}
Z_{11} &= Z_{11a} + jZ_{11b} \\
Z_{12} &= Z_{12a} + jZ_{12b} \qquad (14) \\
Z_{22} &= Z_{22a} + jZ_{22b}
\end{aligned}
$$

Substitute (14) to (12) we get

$$\cancel{(g_1 + j\omega c_1)(Z_{11a} + jZ_{11b}) = r_1(g_1} + j\omega c_1) + 1 - (g_2 + j\omega c_2)(Z_{12a} + jZ_{12b})$$

$$g_1Z_{11a} - \omega c_1Z_{11b} + j(g_1Z_{11b} + Z_{11a}\omega c_1) = r_1g_1 + 1 - g_2Z_{12a} + \omega c_2Z_{12b} + j(r_1\omega c_1 - \omega c_2Z_{12a} - g_2Z_{12b}) \qquad (15)$$

By separate real and imaginary part, we get two equations,

$$g_1Z_{11a} - \omega c_1Z_{11b} - r_1g_1 - 1 + g_2Z_{12a} - \omega c_2Z_{12b} = 0 \qquad (16)$$

$$g_1Z_{11b} + Z_{11a}\omega c_1 - r_1\omega c_1 + \omega c_2Z_{12a} + g_2Z_{12b} = 0 \qquad (17)$$

Be substituting (14) to (13) we can get another two equations in a similar way,

$$g_2Z_{22a} - \omega c_2Z_{22b} - r_2g_2 - 1 + g_1Z_{12a} - \omega c_1Z_{12b} = 0 \qquad (18)$$

$$g_2Z_{22b} + Z_{22a}\omega c_2 - r_2\omega c_2 + \omega c_1Z_{12a} + g_1Z_{12b} = 0 \qquad (19)$$

When the measurements are taken at two frequencies, we can get another set of equation at frequency ω_2, if we denote the measurements at this frequency by adding a superscript 2 to the corresponding quantities. the equations can be written as follows

$$g_1Z^2_{11a} - \omega_2c_1Z^2_{11b} - r_1g_1 - 1 + g_2Z^2_{12a} - \omega_2c_2Z^2_{12b} = 0 \qquad (20)$$

$$g_1Z^2{}_{11b} + Z^2{}_{11a}\omega_2c_1 - r_1\omega_2c_1 + \omega_2c_2Z^2{}_{12a} + g_2Z^2{}_{12b} = 0 \qquad (21)$$

$$g_2Z^2{}_{22a} - \omega_2c_2Z^2{}_{22b} - r_2g_2 - 1 + g_1Z^2{}_{12a} - \omega_2c_1Z^2{}_{12b} = 0 \qquad (22)$$

$$g_2Z^2{}_{22b} + Z^2{}_{22a}\omega_2c_2 - r_2\omega_2c_2 + \omega_2c_1Z^2{}_{12a} + g_1Z^2{}_{12b} = 0 \qquad (23)$$

The problem is to solve equations (16) to (23) for model parameters r_k, g_k and c_k, $k=1,2$.
To eliminate r_1 and r_2, first let (16) − (20), we get,

$$g_1(Z_{11a} - Z^2_{11a}) - c_1(\omega Z_{11b} - \omega_2Z^2_{11b}) + g_2(Z_{12a} - Z^2_{12a}) - c_2(\omega Z_{12b} - \omega_2Z^2_{12b}) = 0 \qquad (24)$$

then $\omega_2\times(17) - \omega\times(21)$ which gives,

$$g_1(\omega_2Z_{11b} - \omega Z^2_{11b}) - \omega\,\omega_2c_1(Z_{11a} - Z^2_{11a}) + g_2(\omega_2Z_{12b} - \omega Z^2_{12b}) - \omega\,\omega_2c_2(Z_{12a} - Z^2_{12a}) = 0 \qquad (25)$$

similarly, (12) − (16) yields,

$$g_2(Z_{22a} - Z^2_{22a}) - c_2(\omega Z_{22b} - \omega_2Z^2_{22b}) + g_1(Z_{12a} - Z^2_{12a}) - c_1(\omega Z_{12b} - \omega_2Z^2_{12b}) = 0 \qquad (26)$$

Let,

$$a_1 = Z_{11a} - Z^2_{11a} \qquad (27)$$

$$a_2 = Z_{12a} - Z^2_{12a} \qquad (28)$$

$$a_3 = Z_{22a} - Z^2_{22a} \qquad (29)$$

and

$$b_1 = \omega Z_{11b} - \omega_2Z^2_{11b} \qquad (30)$$

$$b_2 = \omega_2Z_{11b} - \omega Z^2_{11b} \qquad (31)$$

$$b_3 = \omega Z_{12b} - \omega_2Z^2_{12b} \qquad (32)$$

$$b_4 = \omega_2 Z_{12b} - \omega Z_{12b}^2 \tag{33}$$

$$b_5 = \omega Z_{22b} - \omega_2 Z_{22b}^2 \tag{34}$$

$$b_6 = \omega_2 Z_{22b} - \omega Z_{22b}^2 \tag{35}$$

So (24) to (26) can be rewritten as

$$a_1 g_1 - b_1 c_1 + a_2 g_2 - b_3 c_2 = 0 \tag{36}$$

$$b_2 g_1 + a_1 \omega\omega_2 c_1 + b_4 g_2 + a_2 \omega\omega_2 c_2 = 0 \tag{37}$$

$$a_3 g_2 - b_5 c_2 + a_2 g_1 - b_3 c_1 = 0 \tag{38}$$

Solve (36) to (38) for g_1, c_1, and c_2 we get,

$$g_1 = -\frac{a_1 a_2 b_5 \omega\omega_2 + b_2 b_4 b_5 - (b_3)^2 b_4 + a_2 a_3 b_1 \omega\omega_2 - a_1 a_3 b_3 \omega\omega_2 - (a_2)^2 b_3 \omega\omega_2}{\Delta_1} g_2 \tag{39}$$

$$\cancel{c_1 = -\frac{a_1 b_4 b_5 + a_1 a_2 a_3 \omega\omega_2 - a_2 b_2 b_5 - (a_2)^3 \omega\omega_2 - a_2 b_2 b_4 + a_2 b_2 b_3}{\Delta_1} g_2} \tag{40}$$

$$c_2 = \frac{-a_2 b_1 b_4 + a_3 b_1 b_2 - a_1 (a_2)^2 \omega\omega_2 - a_2 b_2 b_3 + (a_1)^2 a_3 \omega\omega_2 + a_1 b_3 b_4}{\Delta_1} g_2 \tag{41}$$

where

$$\Delta_1 = b_1 b_2 b_5 + (a_1)^2 b_5 \omega\omega_2 - b_2 (b_3)^2 + (a_2)^2 b_1 \omega\omega_2 - 2 a_1 a_2 b_3 \omega\omega_2 \tag{42}$$

If we denote the coefficient of (39)-(41) by n_j, $j=1, 2, 3$, we get,

$$g_1 = n_1 g_2 \tag{43}$$

$$c_1 = n_2 g_2 \tag{44}$$

$$c_2 = n_3 g_2 \tag{45}$$

where

$$n_1 = -\frac{a_1 a_2 b_5 \omega\omega_2 + b_2 b_4 b_5 - (b_3)^2 b_4 + a_2 a_3 b_1 \omega\omega_2 - a_1 a_3 b_3 \omega\omega_2 - (a_2)^2 b_3 \omega\omega_2}{\Delta_1} \tag{46}$$

$$n_2 = -\frac{a_1 b_4 b_5 + a_1 a_2 a_3 \omega\omega_2 - a_2 b_2 b_5 - (a_2)^3 \omega\omega_2 - a_2 b_2 b_4 + a_2 b_2 b_3}{\Delta_1} \tag{47}$$

$$n_3 = \frac{-a_2 b_1 b_4 + a_3 b_1 b_2 - a_1 (a_2)^2 \omega\omega_2 - a_2 b_2 b_3 + (a_1)^2 a_3 \omega\omega_2 + a_1 b_3 b_4}{\Delta_1} \tag{48}$$

Substitute g_1, c_1, c_2 to (17)

$$n_1 g_2 Z_{11b} + Z_{11a} \omega n_2 g_2 - r_1 \omega n_2 g_2 + \omega n_3 g_2 Z_{12a} + g_2 Z_{12b} = 0 \tag{49}$$

if $g_2 \neq 0$, we can solve (49) for r_1 as follows

$$r_1 = \frac{n_1 Z_{11b} + Z_{11a} \omega n_2 + \omega n_3 Z_{12a} + Z_{12b}}{\omega n_2} \tag{50}$$

Similarly we can get r_2 from (19)

$$r_2 = \frac{n_1 Z_{11b} + Z_{22a} \omega n_3 + \omega n_2 Z_{12a} + Z_{22b}}{\omega n_3} \tag{51}$$

Substitute g_1, c_1, c_2 and r_1 to (16), we can determine g2,

$$g_2 = -\frac{\omega n_2}{(n_1)^2 Z_{11b} + n_1 n_3 Z_{12a} \omega + n_1 Z_{12b} - n_2 Z_{12a} \omega + n_2 n_3 Z_{12b} (\omega)^2 + (n_2)^2 Z_{11b} (\omega)^3} \tag{52}$$

After g_2 is determined, g_1, c_1, c_2 can be calculated from (43) to (45). So far, the only parameter left undetermined is Z, which can be calculated at frequency ω from (10) as

$$Z = \frac{\frac{1}{Z_{12}} - g_1 - g_2 - j\omega c_1 - j\omega c_2}{(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \tag{53}$$

Appendix 3

Further discussions on Identification Results

In Appendix 2 we got a set of symbolic solutions to all the parameters in the enhanced model. The results are repeated here,

$$r_1 = \frac{n_1 Z_{11b} + Z_{11a}\omega n_2 + \omega n_3 Z_{12a} + Z_{12b}}{\omega n_2} \quad (1)$$

$$r_2 = \frac{n_1 Z_{11b} + Z_{22a}\omega n_3 + \omega n_2 Z_{12a} + Z_{22b}}{\omega n_2} \quad (2)$$

$$g_2 = -\frac{\omega n_2}{(n_1)^2 Z_{11b} + n_1 n_3 Z_{12a}\omega + n_1 Z_{12b} - n_2 Z_{12a}\omega + n_2 n_3 Z_{12b}(\omega)^2 + (n_2)^2 Z_{11b}(\omega)^3} \quad (3)$$

$$g_1 = n_1 g_2$$

$$c_1 = n_2 g_2 \quad (4)$$

$$c_2 = n_3 g_2 \quad (5)$$

$$Z = \frac{\frac{1}{Z_{12}} - g_1 - g_2 - j\omega c_1 - j\omega c_2}{(g_1 + j\omega c_1)(g_2 + j\omega c_2)} \quad (6)$$

where ω is test frequency, Z_{ija} and Z_{ijb}, $i=1,2$, $j=1,2$ are the real and imaginary parts of the Z-parameters respectively, and n_k, $k=1,2,3$ can be calculated as follows,

$$n_1 = -\frac{a_1 a_2 b_5 \omega\omega_2 + b_1 b_4 b_5 - (b_3)^2 b_4 + a_2 a_3 b_1 \omega\omega_2 - a_1 a_3 b_3 \omega\omega_2 - (a_2)^2 b_3 \omega\omega_2}{\Delta_1} \quad (7)$$

$$n_2 = -\frac{a_1 b_4 b_5 + a_1 a_2 a_3 \omega\omega_2 - a_2 b_2 b_5 - (a_2)^3 \omega\omega_2 - a_2 b_3 b_4 + a_2 b_2 b_3}{\Delta_1} \quad (8)$$

$$n_3 = \frac{-a_2 b_1 b_4 + a_3 b_1 b_2 - a_1 (a_2)^2 \omega\omega_2 - a_2 b_2 b_3 + (a_1)^2 a_3 \omega\omega_2 + a_1 b_3 b_4}{\Delta_1} \quad (9)$$

where

$$\Delta_1 = b_1 b_2 b_5 + (a_1)^2 b_5 \omega\omega_2 - b_2 (b_3)^2 + (a_2)^2 b_1 \omega\omega_2 - 2 a_1 a_2 b_3 \omega\omega_2 \quad (10)$$

and a_k, k=1,2,3, b_j, j=1…6 can be calculated directly from the knowns(See [1] for their definations)

One problem with this set of formula is that Δ_1 can be zero for some particular measurement values. In this case, an alternative has to be found to calculate the parameters. Taking into

consideration the condition that Δ_1 is zero, another set of formula can be obtained as shown in the follows.

$$r_1 = -\frac{-Z_{11a}\omega a_2 b_5 + Z_{11a}\omega a_3 b_3 - Z_{12b} b_1 b_5 + Z_{12b}(b_3)^2 - Z_{12a}\omega a_3 b_1 + Z_{12a}\omega a_2 b_3}{\omega(a_2 b_5 - a_3 b_3)} \tag{11}$$

$$r_2 = \frac{Z_{22a}\omega a_1 b_3 - Z_{22a}\omega a_2 b_1 - Z_{12b} b_1 b_5 + Z_{12b}(b_3)^2 - Z_{12a}\omega a_1 b_5 + Z_{12a}\omega a_2 b_3}{\omega(a_1 b_3 - a_2 b_1)} \tag{11}$$

$$g_2 = \frac{s_2 - m_2}{m_1 s_2 - m_2 s_1} \tag{13}$$

$$c_2 = \frac{m_1 - s_1}{m_1 s_2 - m_2 s_1} \tag{14}$$

$$c_1 = q_1 c_2 + q_2 g_2 \tag{15}$$

$$c_1 = p_1 c_2 + p_2 g_2 \tag{16}$$

where

$$m_1 = Z_{11a} p_2 - \omega Z_{11b} q_2 - r_1 p_2 + Z_{12a} \tag{17}$$

$$m_2 = Z_{11a} p_1 - \omega Z_{11b} q_1 - r_1 p_1 + \omega Z_{12b} \tag{18}$$

$$s_1 = Z_{22a} - r_2 + Z_{12a} p_2 - \omega Z_{12b} q_2 \tag{19}$$

$$s_2 = -\omega Z_{22b} + Z_{12a} p_1 - \omega Z_{12b} q_1 \tag{20}$$

and

$$p_1 = \frac{(b_3)^2 - b_1 b_5}{a_1 b_3 - a_2 b_1} \tag{21}$$

$$p_2 = \frac{a_3 b_1 - a_2 b_3}{a_1 b_3 - a_2 b_1} \tag{22}$$

$$q_1 = \frac{a_2 b_3 - a_1 b_5}{a_1 b_3 - a_2 b_1} \tag{23}$$

$$q_2 = \frac{a_1 a_3 - (a_2)^2}{a_1 b_3 - a_2 b_1} \tag{24}$$

Appendix 4

Line termination

The line is usually terminated by a resistance R in series with a capacitor C, which is paralleled by the loop resistance and capacitors. To determine the termination is to identify all these parameters. In Appendix 1 and 2 we have got the equivalent impedance Z or admittance of the termination Y at two frequencies when we identify the model parameters. We now considering using admittance representation. From Figure 9 we have

$$Y = g + j\omega c_1 + \frac{j\omega c_2}{1 + j\omega R c_2} \tag{1}$$

Let

$$Y = a + jb \tag{2}$$

where a and b are the real and imaginary part of Y respectively. So

$$a = g + \frac{\omega^2 R c_2^2}{1 + \omega^2 R^2 c_2^2} \tag{3}$$

$$b = \omega c_1 + \frac{\omega c_2}{1 + \omega^2 R^2 c_2^2} \tag{4}$$

Let

$$Rc_2 = x \tag{5}$$

and measure the Y at two frequencies ω_1 and ω_1. we have

$$a_1 - a_2 = \frac{\omega_1^2 x c_2}{1 + \omega_1^2 x^2} - \frac{\omega_2^2 x c_2}{1 + \omega_2^2 x^2} \tag{6}$$

and

$$\frac{b_1}{\omega_1} - \frac{b_2}{\omega_2} = \frac{c_2}{1 + \omega_1^2 x^2} - \frac{c_2}{1 + \omega_2^2 x^2} \tag{7}$$

(6)/(7) we have

$$\begin{aligned}\frac{a_1 - a_2}{\dfrac{b_1}{\omega_1} - \dfrac{b_2}{\omega_2}} &= \frac{\dfrac{\omega_1^2 x}{1+\omega_1^2 x^2} - \dfrac{\omega_2^2 x}{1+\omega_2^2 x^2}}{\dfrac{1}{1+\omega_1^2 x^2} - \dfrac{1}{1+\omega_2^2 x^2}} \\ &= x\frac{\omega_1^2(1+\omega_2^2 x^2) - \omega_2^2(1+\omega_1^2 x^2)}{(1+\omega_2^2 x^2) - (1+\omega_1^2 x^2)} \\ &= x\frac{\omega_1^2 - \omega_2^2}{\omega_2^2 x^2 - \omega_1^2 x^2} \\ &= -\frac{1}{x}\end{aligned} \tag{8}$$

i.e.

$$x = -\frac{\dfrac{b_1}{\omega_1} - \dfrac{b_2}{\omega_2}}{a_1 - a_2} = \frac{1}{\omega_1 \omega_2}\frac{\omega_2 b_1 - \omega_1 b_2}{a_2 - a_1} \tag{9}$$

After we get x, c_2 can be calculated from (6), which gives

$$c_2 = \frac{(a_1 - a_2)(1+\omega_1^2 x^2)(1+\omega_2^2 x^2)}{x(\omega_1^2 - \omega_2^2)} \tag{10}$$

and R from (5)

$$R = \frac{x}{c_2} \tag{11}$$

So g and c1 can be determined from (3) and (4) respectively

$$g = a_1 - \frac{\omega_1^2 x c_2^2}{1+\omega_1^2 x^2} \tag{12}$$

and

$$c_1 = \frac{b_1}{\omega_1} - \frac{c_2}{1+\omega_1^2 x^2} \tag{13}$$

CLAIMS

1. A method of testing a telecommunications system, the method comprising;

1) applying a first AC test signal having a first signal frequency to the system and measuring the response of the system to the first test signal;

2) applying a second AC test signal having a second signal frequency different to the first signal frequency to the system and measuring the response of the system to the second test signal; and

3) calculating one or more parameters of the system from the responses measured in steps 1) and 2).

2. A method according to claim 1 wherein the first and second test signals are applied at different times.

3. A method according to claim one or two wherein one or both of the test signals has a substantially sinusoidal waveform.

4. A method according to any of the preceding claims wherein less than five cycles of each signal is applied to the system.

5. A method according to any of the preceding claims wherein the test signals are each applied to the system through a known impedance.

6. A method according to any of the preceding claims further comprising applying;

4) applying one or more additional test signals to the system and measuring the response of the system to the or each test signal; and

wherein step 3) comprises calculating one or more parameters of the system from the responses measured in steps 1),2) and 4).

7. A method according to any of the preceding claims wherein the system comprises first and second transmission lines, and wherein each step of applying a test signal and measuring the response of the system comprises

a) applying the test signal to the first line and monitoring the response of the first line and the second line to the test signal; and

b) applying the test signal to the second line and monitoring the response of the second line and the first line to the second test signal.

8. A method of testing a telecommunications system comprising first and second transmission lines, the method comprising

1) applying a first test signal to the first line and measuring the response of the first line and the second line to the first test signal;

2) applying a second test signal to the second line and measuring the response of the second line and the first line to the second test signal; and

3) calculating one or more parameters of the telecommunications system from the responses measured in steps 1) and 2).

9. A method according to any claim 8 wherein the first and second signals each comprise AC signals.

10. A method according to claim 9 wherein the signal frequencies of the first and second test signals are substantially identical.

11. A method according to claim 10 wherein the first and second test signals have a known phase relationship.

12. Apparatus for testing a telecommunications system, the apparatus comprising;

1) means for applying a first AC test signal having a first signal frequency to the system;

2) means for measuring the response of the system to the first test signal;

3) means for applying a second AC test signal having a second signal frequency different to the first signal frequency to the system;

4) means for measuring the response of the system to the second test signal; and

5) means for calculating one or more parameters of the system from the responses measured in steps 1) and 2).

13. Apparatus for testing a telecommunications system comprising first and second transmission lines, the apparatus comprising

1) means for applying a first test signal to the first line

2) means for measuring the response of the first line and the second line to the first test signal;

3) means for applying a second test signal to the second line

4) means for measuring the response of the second line and the first line to the second test signal; and

5) means for calculating one or more parameters of the telecommunications system from the responses measured in steps 1) and 2).

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(54) Title: APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM

(57) Abstract

A method of testing a telecommunications system (7), the method comprising: 1) applying a first AC test signal having a first signal frequency to the system and measuring the response of the system to the first test signal; 2) applying a second AC test signal having a second signal frequency different to the first signal frequency to the system and measuring the response of the system to the second test signal; and 3) calculating one or more parameters of the system from the responses measured in steps 1) and 2).

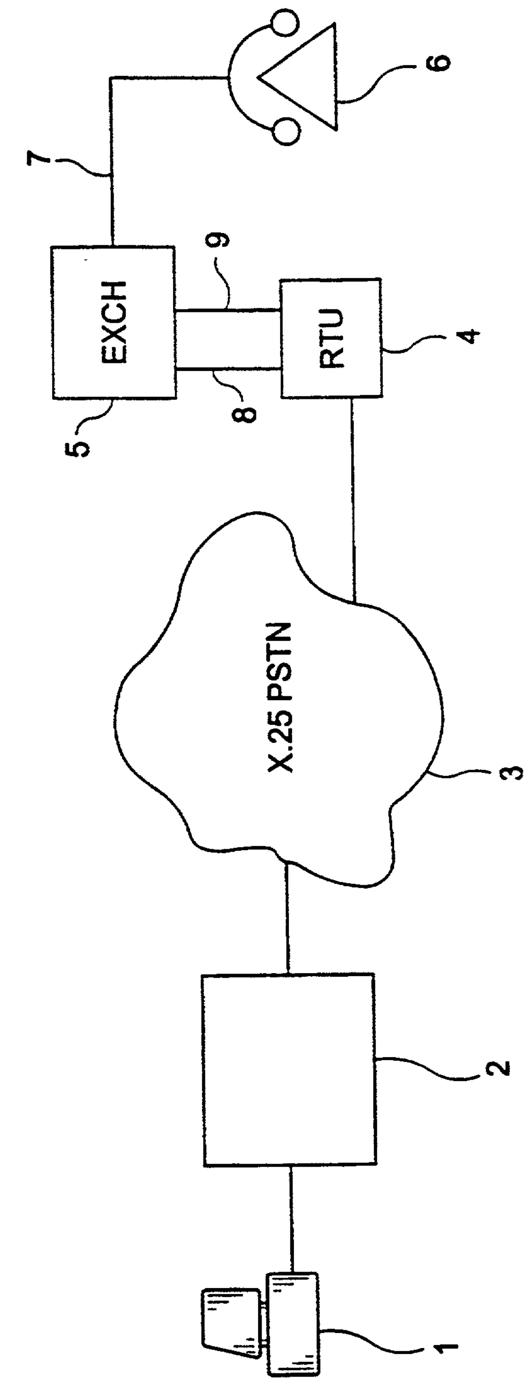


FIG-1

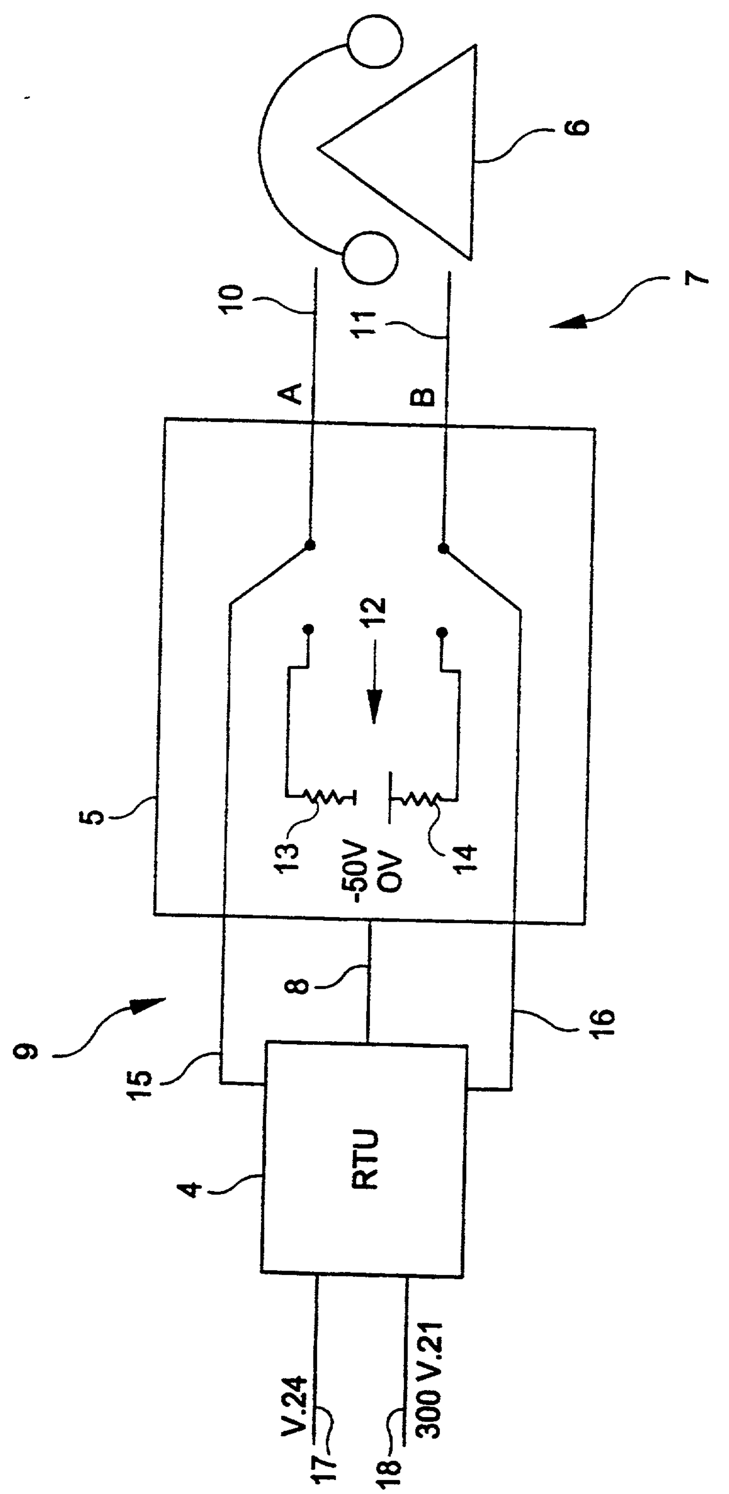


FIG-2

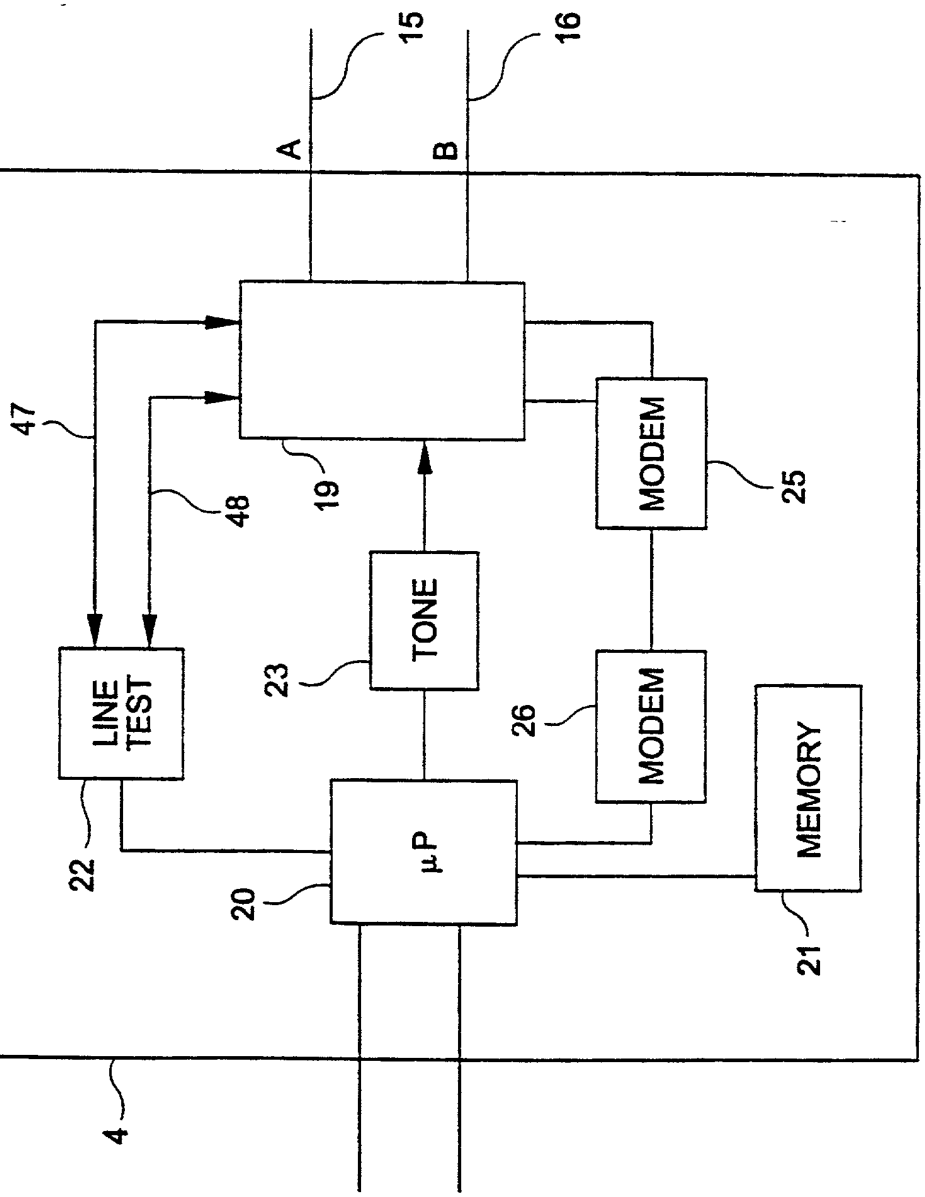

15
16
A
B
47
48
19
LINE TEST
TONE
MODEM
MODEM
MEMORY
µP
22
20
23
26
25
21
4

FIG-3

FIG-4

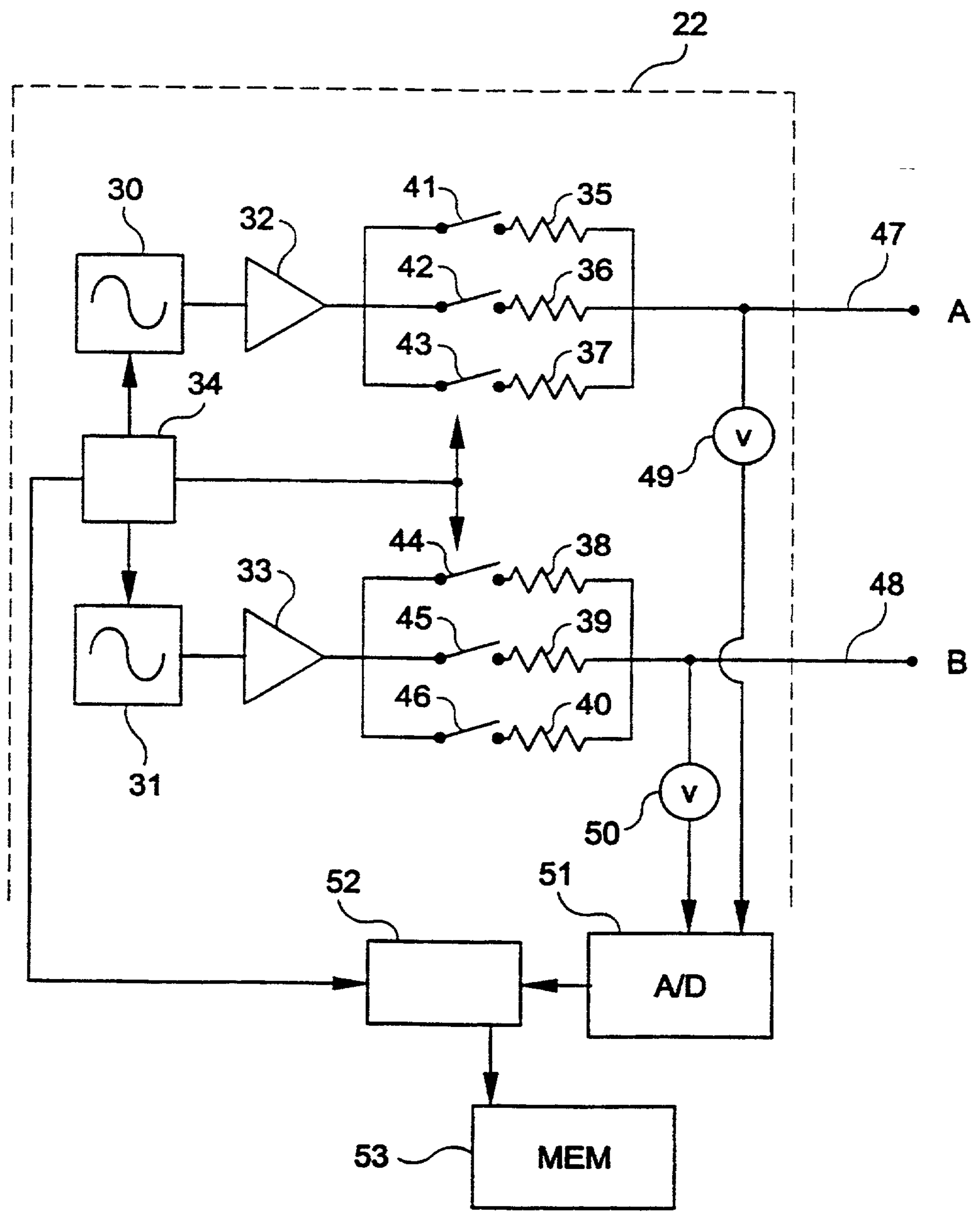
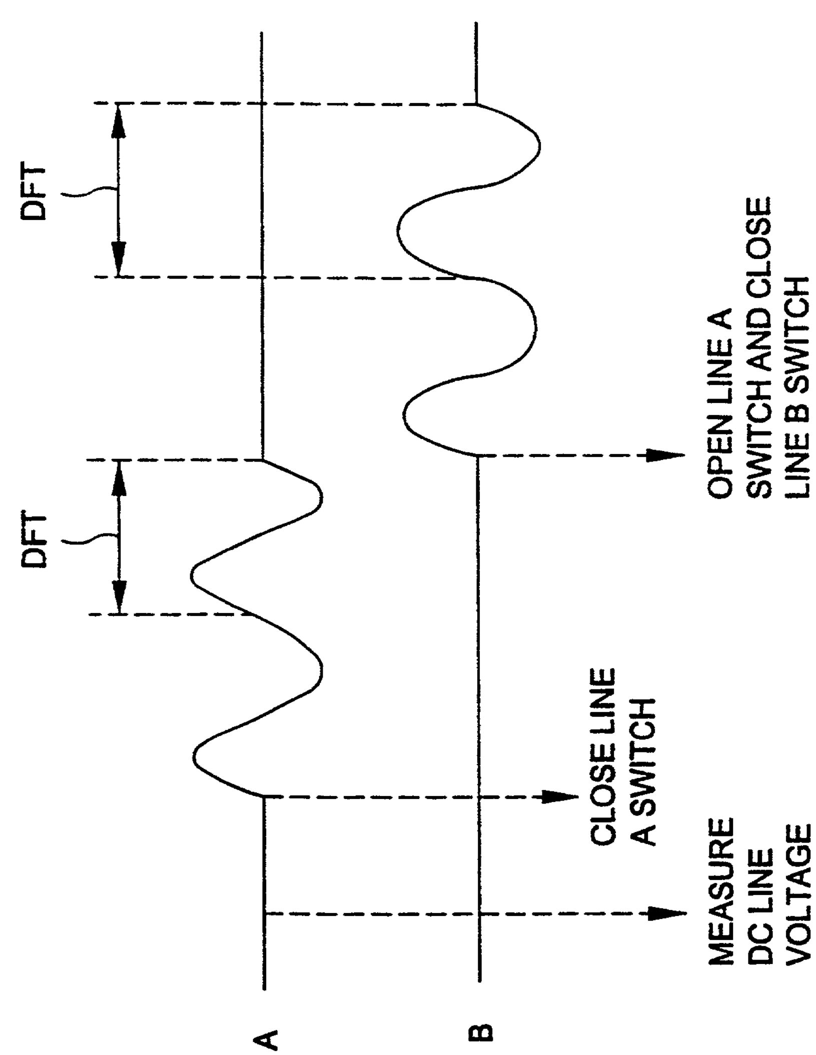

22
30
32
41
35
42
36
43
37
47
A
34
49
V
44
38
33
45
39
48
B
46
40
31
V
50
52
51
A/D
53
MEM

FIG-5


A
B
DFT
DFT
MEASURE DC LINE VOLTAGE
CLOSE LINE A SWITCH
OPEN LINE A SWITCH AND CLOSE LINE B SWITCH

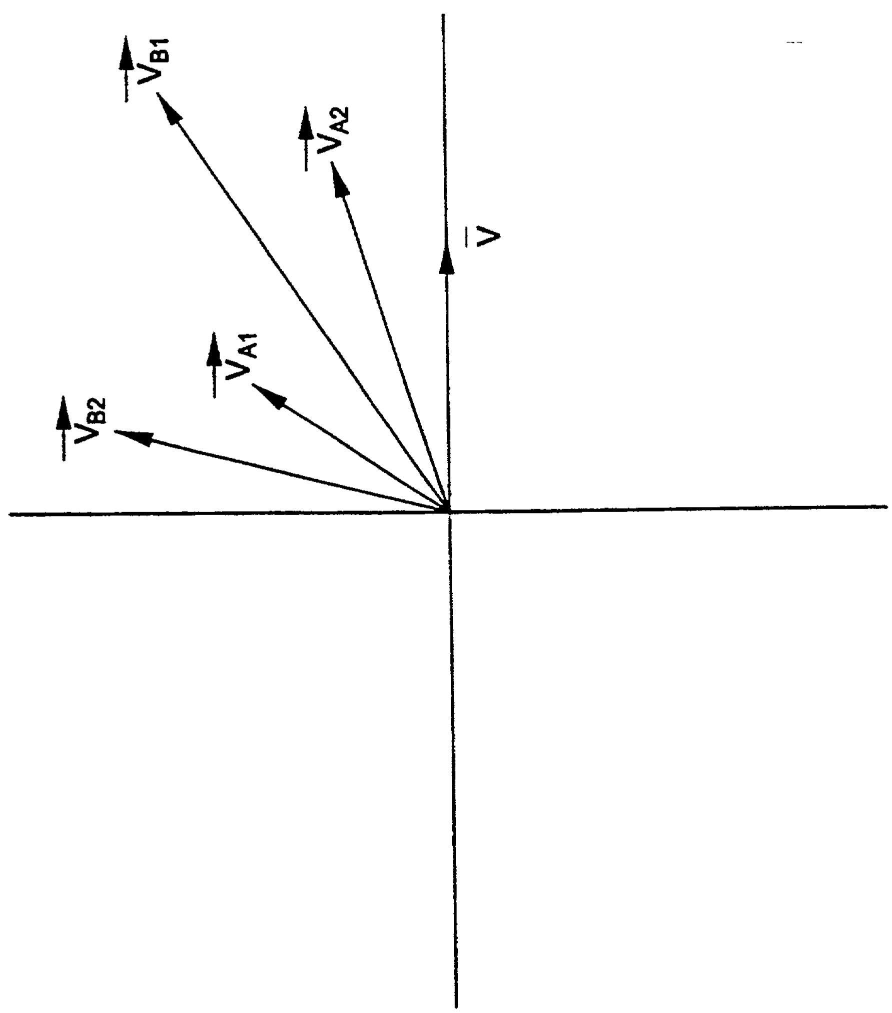


FIG-6

FIG-7

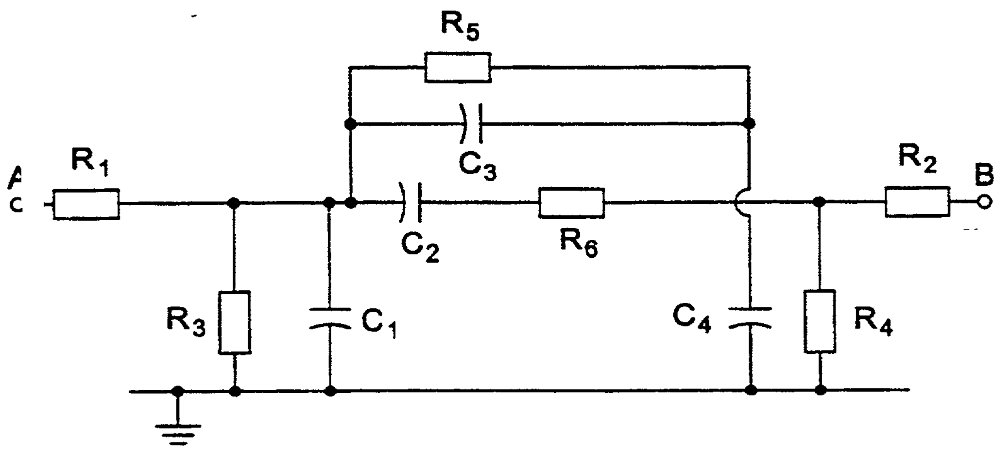


FIG-8

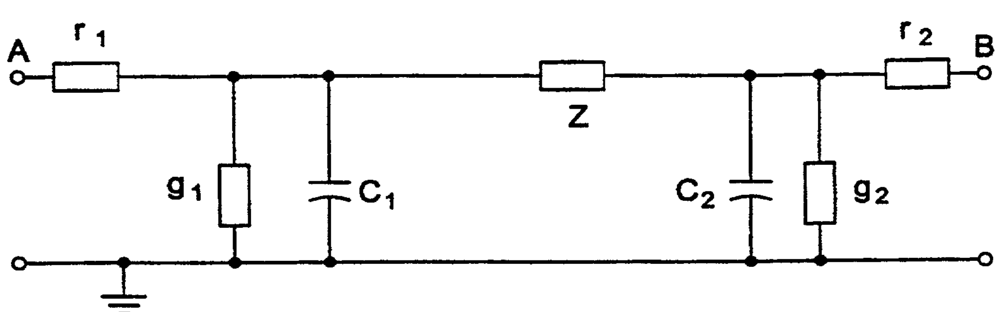


FIG-9

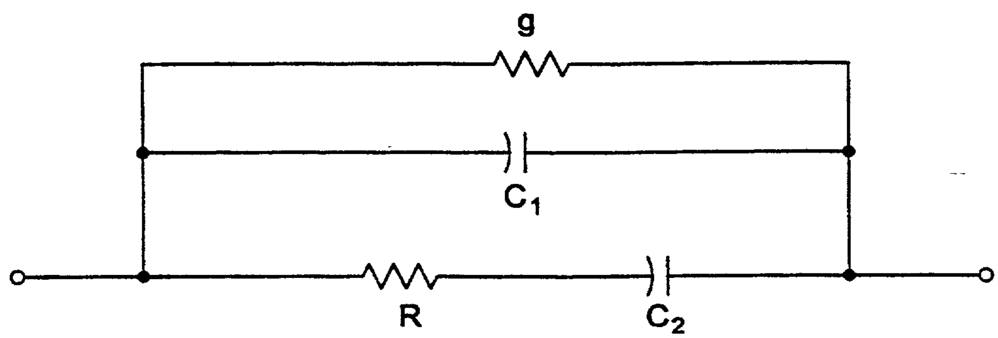
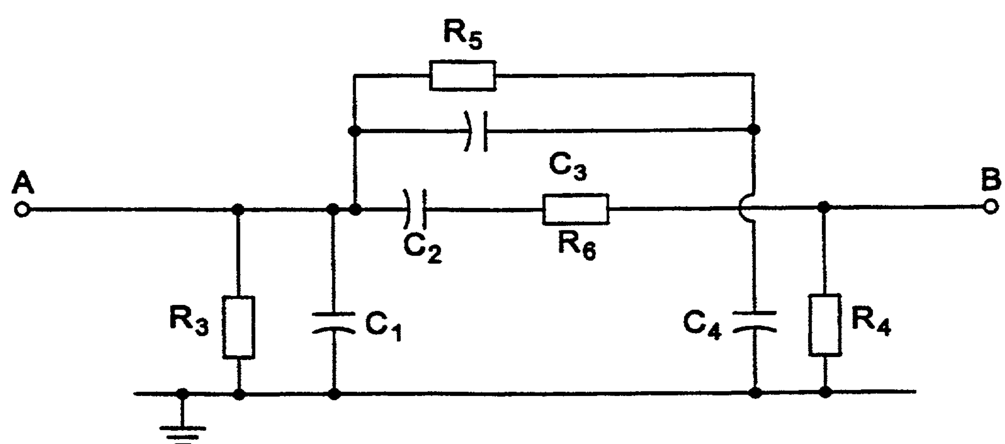


FIG-10



VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) AND 1.27 (c)) - SMALL BUSINESS CONCERN			Docket No. 587-68 EPO/PCT/US
Serial No. PCT/US99/11617	Filing Date May 26, 1999	Patent No.	Issue Date

Applicant/ Patentee: **Robert De Tullio, et al.**

Invention: **APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM**

I hereby declare that I am:

- ☒ the owner of the small business concern identified below:
- ☐ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: **Porta Systems Corporation**
ADDRESS OF CONCERN: **575 Underhill Boulevard, Syosset, New York 11791**

I hereby declare that the above-identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the above identified invention described in:

- ☐ the specification filed herewith with title as listed above.
- ☒ the application identified above.
- ☐ the patent identified above.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed on the next page and no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under 37 CFR 1.9(c) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

☒ no such person, concern or organization exists.
☐ each such person, concern or organization is listed below.

FULL NAME
ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME
ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME
ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME
ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING: **William V. Carney**

TITLE OF PERSON SIGNING OTHER THAN OWNER: **Chairman of the Board and Chief Executive Officer**

ADDRESS OF PERSON SIGNING: **575 Underhill Boulevard**
Syosset, New York 11791

SIGNATURE: William V. Carney DATE: 12-21-00

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

APPARATUS AND METHOD FOR TESTING A TELECOMMUNICATIONS SYSTEM

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on May 26, 1999 as United States Application No. or PCT International Application Number PCT/US99/11617 and was amended on ______________ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

(Number)	(Country)	(Day/Month/Year Filed)	Priority Not Claimed
98304171.6	EPO	27 May 1998	☐
			☐
			☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional

(Application Serial No.) (Filing Date)

(Application Serial No.) (Filing Date)

(Application Serial No.) (Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.) (Filing Date) (Status) (patented, pending, abandoned)

(Application Serial No.) (Filing Date) (Status) (patented, pending, abandoned)

(Application Serial No.) (Filing Date) (Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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1-00

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3-00

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4-00

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Full name of fifth inventor, if any	
Fifth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	

Full name of sixth inventor, if any	
Sixth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	